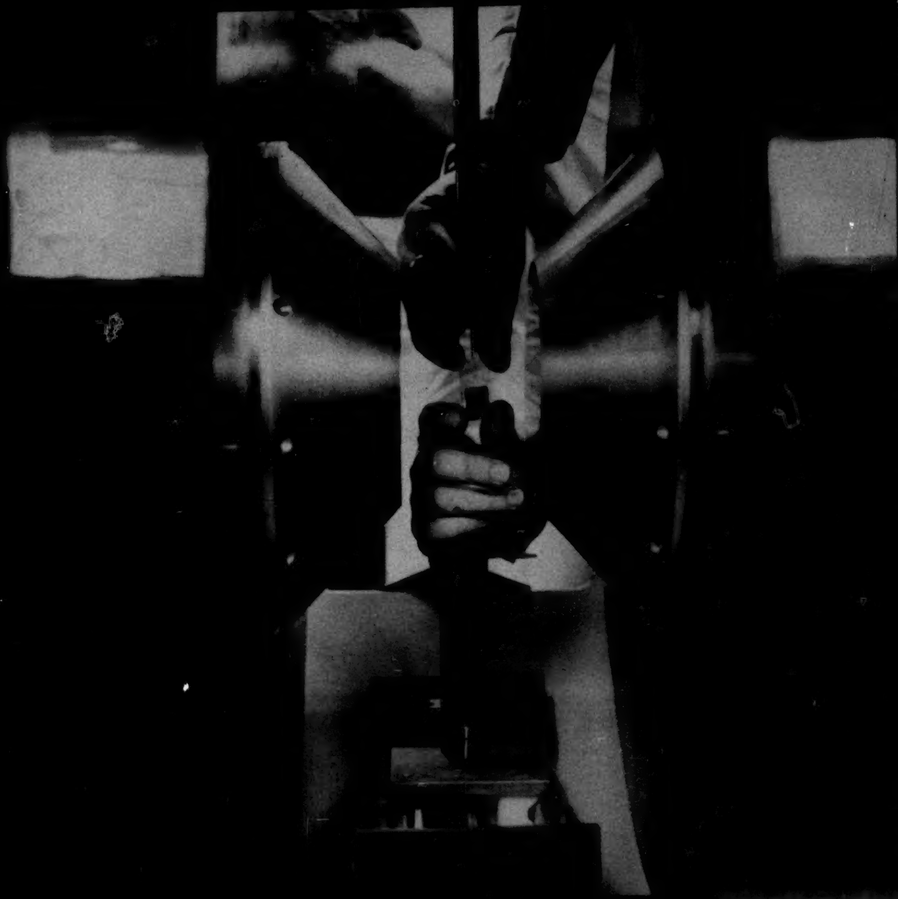

THE

RESEARCH ENGINEER

DECEMBER, 1961

The First of A Special Series on Solid State Research

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The Cover

In Tech's School of Physics, gigantic magnets, capable of producing fields up to 10,000 gauss, are used to investigate the magnetic properties of thin metal films.

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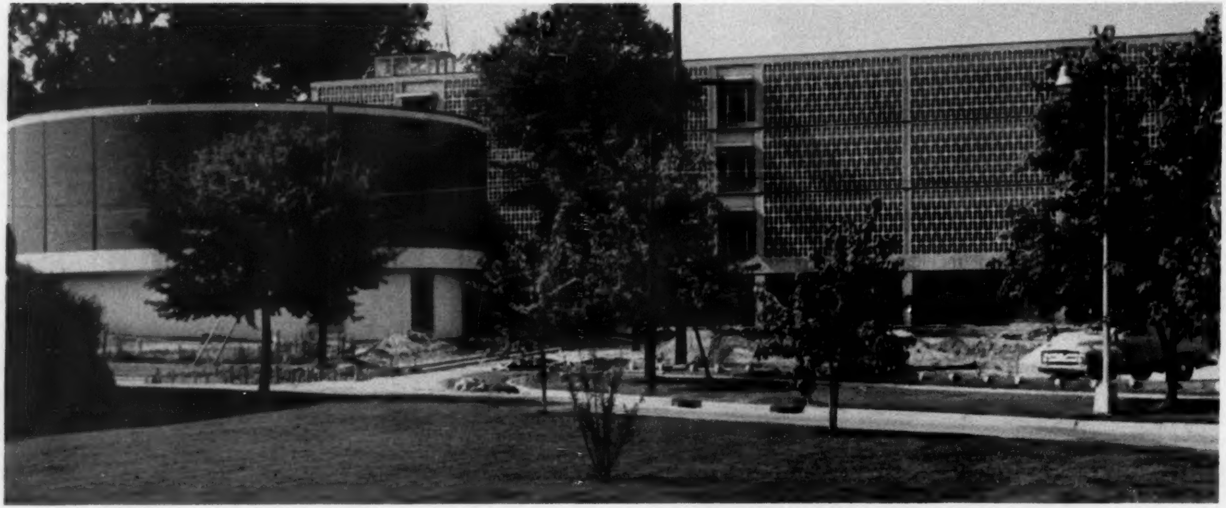
NEW INSIGHTS, NEW TECHNIQUES, NEW HORIZONS

by William B. Jones, Jr.



NOT SINCE the period which followed DeForest's invention of the triode vacuum tube more than 50 years ago has any series of developments had such a spectacular effect on the field of electrical engineering as the progress in solid state technology during the last ten years.

Because of the diverse ways in which solid state devices are being applied, the long range effects of this progress may well be even more important than the developments which followed the invention of the vacuum tube.

To the electrical engineer, the words "solid state electronics" may mean a variety of things. To many they mean semiconductors, their electrical properties, and semiconductor devices such as transistors, diodes, solar cells, photosensitive devices and many others. To others, they may also include non-linear magnetic and dielectric materials, molecular amplifiers, etc. A much broader and more comprehensive definition, still from the restricted point of view of the electrical engineer, might be "the study of the electric and magnetic properties of solid materials and the devices which make use of these properties." The effects of light, heat, mechanical stress and many other phenomena on these properties and the mutual interactions between various combinations of these causes and effects are sometimes an important part of this study.

Instructions scheduled in Tech's New Electrical Engineering Building Reflect Increasing Importance of Solid State Science.

The most widely publicized advances in the field of solid state electronics thus far have been in transistors and related semiconductor devices. Semiconductors—materials which are neither good conductors nor good insulators — had found a number of useful applications and there had been some speculation about the possibilities of a solid state amplifier when scientists discovered the properties which led to the transistor. The development of the transistor was indeed a spectacular accomplishment. Drs. J. Bardeen and W. H. Brattain, who first disclosed the discovery of transistor action, and Dr. W. Shockley, who subsequently invented the junction transistor, were the joint recipients of the Nobel Prize in Physics in 1956.

Microsystems electronics is a term used to describe efforts to achieve electronic equipment of reduced size and weight, more efficient power utilization, increased reliability and lower cost. The approach usually taken is to incorporate as

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many circuit or system functions as possible into one block of solid material, usually a semiconductor. A complete circuit function, such as an amplifier or a multivibrator, may be fabricated from a single wafer of a suitable semiconductor. Complex devices, consisting of a combination of several basic devices such as transistors, diodes and solar cells in one solid structure, have been produced in a variety of forms. The importance of the small, efficient and reliable systems which can be built using semiconductor devices and the related techniques of microsystems electronics can be appreciated by considering how much more instrumentation and control equipment can be put into a satellite using these devices than would be possible without them.

Another important recent advance in materials technology has been the development of the Maser. (The name MASER is an acronym for Microwave Amplification by the Stimulated Emission of Radiation.) The Maser is a principal development of the field which has been called Quantum Electronics, an aspect of materials science which includes, but is not limited to, solids. The microwave Maser has already found important applications as a low-noise amplifier and a frequency standard. The more recently developed Optical Maser (or Laser) makes possible for the first time the generation and amplification of coherent light.

The history of the invention of the Maser is interesting because it illustrates how progress in materials science can lead to the systematic development of useful devices. The fundamental principles of the Maser were known to all modern physicists. When the materials and techniques required to achieve stimulated emission began to be understood, the possibility of using this phenomenon for amplification was proposed. In 1951, induced emission was observed in a system similar to that of a Maser, but with a gain well below unity. About three years later the first Maser was operated and since then a variety of types of Masers have been developed.

One measure of the relative importance of a field of specialization is the number of papers published in the technical journals. In the broad field of electrical engineering, several technical periodicals are devoted entirely to solid state science and technology and others devote special issues to subjects within this area. Last year, approximately one third of the papers published in the Proceedings of the Institute of Radio Engineers were on solid state subjects

and in many of the other papers, solid state devices and techniques played an important role.

Such a vigorous and important activity has naturally had an important influence on educational programs. In the School of Electrical Engineering at Georgia Tech, new courses on such subjects as "The Physical Basis of Electron Devices" and "Transistor Circuits" as well as courses in other Schools reflect the increasing importance of solid state technology and materials science. Many courses not specifically devoted to solid state subjects incorporate applications of these devices in the regular classroom and laboratory work.

Faculty and student research programs in solid state and materials sciences are also an important part of the educational program. During the 1960-1961 academic year, five members of the Electrical Engineering faculty participated in research work in this area. Many students, through special problem assignments, graduate theses, and other means, also participated in these programs. Because of the increasing importance of materials science and because of the expanded facilities in the new Electrical Engineering Building, occupied for the first time early this year, it is certain that this research effort will continue to grow both in size and in scope.

DR. WILLIAM B. JONES, JR. received the B. S., M. S. and Ph.D. degrees (electrical engineering) at the Georgia Institute of Technology. A native of Atlanta, his current fields of interest are communications systems, oscillators and digital computers. Jones was a student engineer with the Tennessee Valley Authority and an engineering officer with the U. S. Navy. He also served as a junior engineer with R. I. Sarbacher and Associates and a research engineer with Hughes Aircraft Co. before joining Georgia Tech's faculty. At Hughes Aircraft Jones was project manager responsible for the conception, design, development and evaluation of special communications techniques and systems, primarily for digital communications but including capabilities for digitized voice, conventional voice and facsimile modes of operation. He has served as a staff member at Tech on studies of interference in communications systems and director of projects studying meteortrail propagation phenomena.

solid state / mechanical engineering

A NEW TEACHING APPROACH

by Joseph P. Vidosic

THE RAPID improvement of existing engineering systems and the development of new ones during the past two decades have placed most rigid demands upon materials.

Future demands appear likely to become even more stringent. As a consequence better and new alloys had to be and are being developed. Furthermore, the application of materials to engineering situations has become a much more demanding engineering problem. The impact of all this staggers the engineer not properly trained in this area. He is confronted with a large amount of factual information which he is not really prepared to analyze. He needs to estimate not only the significance of the properties of the materials under consideration for a particular application, but must also evaluate the feasibility and economy of various possibilities of cutting, forming and joining needed to transform materials into required components.

Thus, a fundamental understanding of materials and of material processing is needed. The educational task appears to be that of presenting basic principles which coordinate the total body of knowledge comprising the materials and processing disciplines. Such a unified group of principles, concepts and theories is emerging out of many advances in solid state physics, out of a better understanding of cutting technology, and out of the extensive experimentation being carried out in the processing area.

Serious consideration must be given topic emphasis, science-engineering balance and experiment-demonstration values. Instruction must cover topics dealing with the science of materials, processing concepts, and phenomenological behavior under load and in various other environmental situations. The structure of materials should be covered over the range of atomic to macroscopic, application parameters from mechanical forces to irradiation, phenomenological properties from magnetism to machinability, and technological processing fundamentals from bonding to surface geometry.

To accomplish this task, or at least attempt to accomplish it, Georgia Tech's School of Mechanical Engineering has dropped its previous courses and established a new

DR. JOSEPH P. VIDOSIC, originally from Lovran, Austria, received the M. E. and M. S. degrees at Stevens Institute of Technology, and the Ph.D. at Purdue University. He was a research engineer for Keuffel & Esser Co. and worked in plant engineering with Whitlock Cordage Co. before joining the Tech faculty. During World War II, Vidosic was assistant director, Special Projects Branch; director, A. A. F. Engineering School, for the U. S. A. A. F. Air Material Command, Wright Field. Vidosic, a Regents' professor at Tech, was an instructor in mechanical engineering at Purdue University while studying for the Ph.D. He was a member of the Educational Committee of the American Welding Society and has served on the society's Juri of Awards. His fields of special interest include experimental stress analysis, engineering design, lubrication, vibrations, friction and wear of surface.

series. Each new course consists of two hours of lecture per week plus a three-hour laboratory session. Courses in "Engineering Materials and Processes" are taken during the sophomore year after some physics and calculus have been studied. "Metallurgy and Heat Treating" is taken at the end of the junior year and "Materials Engineering" at the beginning of the senior year.

The first course in "Engineering Materials and Processes" starts with the elements of the nature of metals and proceeds to the study of phases, equilibrium and non-equilibrium phase transformations and heat treatments. Foundry, metalworking and bonding metallurgy and technology are also studied and analyzed. In the laboratory the student performs "experiments" intended to better acquaint him with principles covered in class and provide him with a little experience and "feel" in this area. He views demonstrations and even tries a little joining and metalworking, not to learn these skills but because some engineering value and certainly satisfaction is to be found in the use of the bona fide, basic tools of fabrication.

Because of the lack of suitable text material in the area of metal cutting, the second course in "Engineering Materials and Processes" remains very fluid. Its content is changed from quarter to quarter as notes are written and as experience suggests improvement. However, the philosophy of presentation, topic selection, subject emphasis and science-art balance have been much discussed and practically

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determined. When fully organized about one-third of the class lectures will deal with the function and limitations of machine tools, about one-fifth will consider special non-contact machining techniques and the remaining time will be spent on metallurgy, physics and economics of metal cutting.

Here, too, the laboratory is intended to reinforce acquaintance with principles and techniques being studied. Exercises are designed to first acquaint the student with the basic machine tools so that he can proceed to elementary experimentation in metal cutting. These experiments reveal how surface speeds, feeds, cutting fluids and microstructure affect surface finish, machinability and cutting economics. Work layout and precision measurement, upon which fabrication is so dependent, also constitute the subject matter of very important experiments.

The third course, "Metallurgy and Heat Treating," is basically a metallurgy course dealing with microstructure, its attainment and significance. This was started in the first course in "Engineering Materials and Processes," but is here being covered beyond that point on a broader and deeper basis. Atomic forces—primary and secondary, metallic phases, equilibrium transformations, solid solution precipitation and heat treatment with the resulting property modification through changes in microstructure are each expanded upon and fundamentally analyzed. The proper coverage of this material demands laboratory support. It is believed experiments facilitate a more profound understanding of subject matter. Not only are some exercises planned to prove a principle but others provide direct evidence of the dependence of microstructure and properties upon the mode of treatment.

"Materials Engineering," the last course in the series, is intended to permit interpretation of that studied in the previous courses in terms of aggregates and design value. Environmental factors, phenomenological properties and service behavior under mechanical, thermal, chemical, electromechanical and irradiation conditions are studied. Ceramic and organic material structures are reviewed briefly to acquaint the student with the growing importance of nonmetallics to the mechanical engineer.

Again laboratory exercises are designed to supplement effective class topics. Experiments are planned to provide experience in basic techniques and instrumentation applicable in the area of phenomenological property measurement and material evaluation.

THE FINE STRUCTURE OF MATERIALS

by John L. Brown

FROM THE viewpoint of ultimate structure, solid materials can be classed as either crystals or glasses. Crystals have an orderly array of atoms arranged in a three-dimensional lattice structure; glasses do no display such order. The great majority of solids are crystalline, and solid state physics concerns itself primarily with these.

The properties of crystalline solids depend partly on the nature of the regular atomic structure of the crystals, and partly on the defects which interrupt the regular repeat pattern of the atomic arrangement. The atomic geometry of crystals is best studied by the diffraction of x-rays, electrons and neutrons, but microscopy is more suited to the study of microstructure and imperfections.

The most familiar application of optical microscopy to microstructure studies is in optical metallography, an important tool of the metallurgist. This subject is treated elsewhere in this issue.

A less familiar application is the observation of crystal defects known as dislocations. When a metal crystal is plastically deformed the atomic planes slip over each other like pages in a book when the book is twisted. This slip occurs through the movement of defects known as dislocations. When the surface of the crystal is treated with an etchant the region of intersection of the dislocation with the surface is more readily attacked and a geometrically precise etch pit appears.

The observation of dislocations in the interior of crystals is mostly limited to materials transparent in the visible range; however, a number of visible opaque materials such as silicon can be studied with infrared radiation. If a crystal is supersaturated with a foreign material, the impurity tends to precipitate out more readily along dislocation lines. Thus, the dislocation networks are made visible in three dimensions. This technique is known as decoration.

Slip lines, crystalline steps, and other surface features of slight relief can be readily seen in the reflecting phase contrast microscope. This type of microscope converts small

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optical path-length differences on the surface of the specimen into amplitude contrast differences in the image plane.

The most obvious application of the electron microscope is in complementing and extending observations made with the light microscope. The resolution obtainable is better than 200 times that of the best optical microscope. This high resolution is obtainable only in transmission microscopes. Reflection electron microscopes have a resolving power only slightly greater than optical microscopes but are particularly useful in studying the surface of magnetic materials.

In order to study the surface of a solid opaque to electrons it is necessary to make a thin film replica of the surface and view this by transmission. Some replica techniques have been developed to a high degree of perfection and are capable of revealing surface features in the range of 10 to 20 angstrom units.

In electron metallography, replica techniques are used to study microstructure of metals; furthermore, replicas can be made to include certain small precipitates and inclusions from the surface so that these may be identified by electron diffraction.

One of the most powerful applications of the electron microscope to solid state studies is in the examination of thin films. Thin films of evaporated or sputtered metals can be readily studied by transmission microscopy and diffraction. It is possible to carry on heating and oxidation studies of such films while they are in the microscope.

Thin films of metals and other solids can also be prepared by sectioning in an ultra-microtome and by precision etching methods. Films prepared by the later method can be stressed to a controlled degree in the microscope and the resulting strain observed.

Strain is a microscopic result of dislocations and slip. A dislocation produces a diffraction anomaly which can be seen as a line in the film. As the film is stressed these lines move and the action can be recorded by cine-photomicrography techniques.

In the past few years electron microscope resolution has improved to the extent that diffraction images of some of the larger crystal lattices can be seen directly. When dislocations are present the defect in lattice structure appears just as predicted by theory. For lattice structures smaller than the resolution limit the overlapping of thin crystals may produce an enlarged representation of the lattice structure known as a moire pattern. Analysis of

these patterns can yield detailed information on the lattice structure.

Biological materials are not normally thought of when considering solid state physics, but viruses exist in a twilight zone as materials possessing the characteristics of life and the crystallinity of solids. Some types of viruses have been broken down into basic chemical components and then reassembled into viable units again. The electron microscope is most important in the study of virus particles since all viruses are too small to be seen in the light microscope.

Georgia Tech has been active in the application of microscopy to solid state physics and material sciences for over ten years. Problems involving thin films, metal surfaces, ceramic bodies, minerals, and biological materials have been studied by optical microscopy, electron microscopy, and electron diffraction. A newly acquired Philips EM-200 electron microscope, one of only sixteen in the United States, provides the means for further refinements in solid state studies. In addition, two other electron microscopes are equipped with special devices for application to solid state problems. An ultra-microtome with a diamond knife is capable of sectioning metals and other hard materials into films only 100 angstrom units thick. A complete metallographic laboratory with facilities for mechanical and electropolishing of metal samples is available. Optical and electron metallography are frequently coordinated and compared.

JOHN L. BROWN's current fields of interest include optical design, electron microscopy, optical microscopy, electron diffraction, acoustics spectroscopy and astronomy. The Atlanta native received the B. S. in physics at Georgia Institute of Technology and pursued graduate work there in physics. Brown served as director of a project to design and construct a transducer and striking device for an electronic tuned-Bell carillon. His acoustics work includes design and construction of ultrasonic equipment for aggregation studies of aerosols, and his recent upper atmosphere physics studies have involved design and use of spectrophotometric equipment and practical application of astronomy. The Electron Microscope and Optical Laboratories which he heads deals in all phases of microscopy as a service and research function, as well as some spectrochemistry and consultation on optical problems.

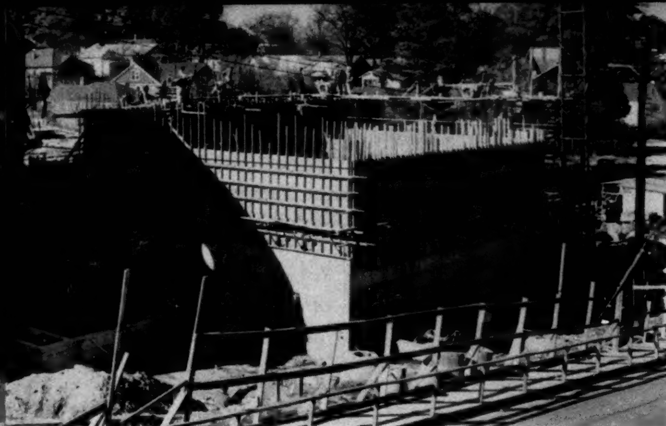
RESEARCH PROGRAM READIED FOR GEORGIA TECH REACTOR

by Michael K. Wilkinson

SOLID STATE RESEARCH WILL PROBABLY BENEFIT

THE GEORGIA TECH Research Reactor, which is scheduled to begin operation in about a year, is a heavy-water-moderated, heterogeneous, enriched fuel reactor, similar to the CP-5 reactor at the Argonne National Laboratory. The reactor will permit operation up to a maximum power level of five megawatts, and at that power it will furnish a neutron flux of approximately 10^{14} neutrons/cm^2/sec.

The most important features of this reactor are the excellent facilities it will make available for experimental research. Numerous horizontal beam holes, penetrating to regions with different neutron characteristics, will be provided, and there will also be a number of vertical holes into the reactor core for irradiations requiring a high flux of high energy neutrons. A thermal column will be available for irradiating large objects with thermal neutrons and pneumatic tubes within some beam holes will allow samples to be removed rapidly from the reactor. In addition, special equipment, including hot cells with remote manipulators



MORE FROM REACTOR THAN ANY OTHER FIELD

and an underwater facility, will be available for handling samples which are highly radioactive, and there will be a large laboratory for biomedical research with special access to the reactor.

Research at a nuclear reactor represents an excellent illustration of interdisciplinary activities which are now observed in many modern research laboratories, because problems can be investigated which are of interest in many different fields of science and engineering. In addition to special experiments in biology and medicine, research programs can include investigations in radiation chemistry, neutron activation analysis, short lived radioactivity, nuclear chemistry, nuclear physics, radiation damage effects, and neutron diffraction. Moreover, related reactor investigations will pertain to reactor kinetics, to reactor engineering problems involving heat transfer and fluid mechanics, and to the development of high temperature reactor fuels and other reactor materials.

Although experimental investigations at a reactor include a large variety of problems, solid state research probably benefits more from a reactor than any other single field of interest. Many different types of investigations that are of particular importance in chemistry, physics, and metallurgy can center around the reactor operation. In general, the investigations can be classified broadly as experiments in which specimens are bombarded by reactor neutrons to change specific properties of the specimens or experiments in which neutrons from the reactor are used as a tool to examine specimens without producing significant changes.

The most numerous contributions of a reactor to solid state research are concerned with experiments of the first

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type, because they include neutron bombardment processes which prepare samples for use in many different types of experimental research. For example, a very important function of a reactor is the economical production of large quantities of radioisotopes for the application of tracer techniques. These techniques, which consist of "tagging" atoms in order to readily follow the courses of reactions that occur in subsequent experiments, have been used in many types of investigations. Another area of solid state research that makes wide use of a reactor involves the studies of radiation damage effects which occur when materials are bombarded by high energy neutrons. These processes introduce defects into the crystal structures of solids, and these defects in turn cause changes in specific properties, such as the electrical conductivity and the critical shear stress. Since many solid state reactions can take place only because of the presence of defects in the crystal structures, these investigations provide important information on the fundamental properties of the bombarded specimens.

Experiments in neutron diffraction are probably the best known solid state investigations which utilize thermal neutrons from a reactor as a tool for research. This technique can be performed successfully *only* at research reactors where high thermal neutron fluxes are available, and up to the present time, almost all of the investigations have been performed in the national laboratories of a few major countries. In its applications to solid state problems neutron diffraction is similar in both theory and experiment to x-ray

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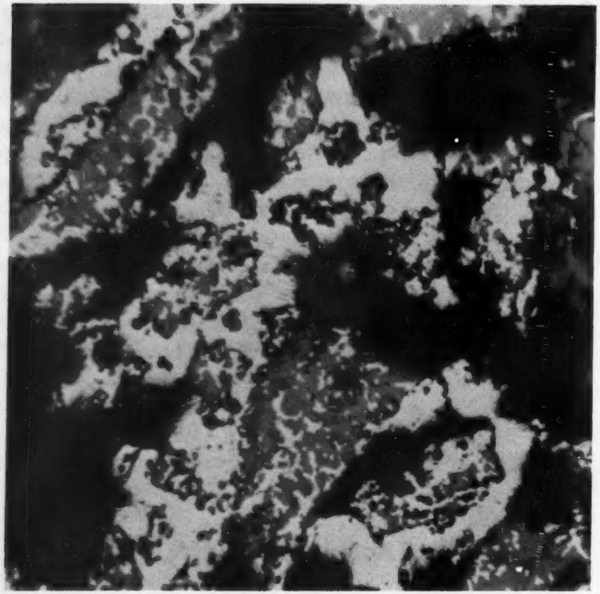
DR. MICHAEL K. WILKINSON, who is on leave of absence from the Oak Ridge National Laboratory, is a recognized world authority in applications of neutron diffraction to solid state problems. He is the first annual Neely Professor at The Georgia Institute of Technology. Dr. Wilkinson is a senior physicist at the Oak Ridge facility and prior to that was a research associate at the Massachusetts Institute of Technology. He is presently conducting a class in the field of neutron diffraction in Tech's School of Physics and his work will be of great value to Georgia Tech in setting up a program for its new nuclear reactor, scheduled for completion in 1962. The Palatka, Fla., native received the B. S. degree at The Citadel and the Ph.D. degree (physics) at the Massachusetts Institute of Technology.

diffraction, but its importance arises from the differences in the two scattering processes. The scattering of x-rays by atoms results from a scattering interaction with the atomic electrons, while neutron scattering involves a short-range nuclear interaction with the atomic nucleus and a magnetic interaction with the magnetic electrons of the atom. In the investigation of chemical and molecular structures, perhaps the most significant neutron diffraction experiments are concerned with structure determinations of composite crystals with both heavy and light atoms, such as compounds containing hydrogen. Whereas other experiments can give little information concerning the position of hydrogen atoms in crystals, this determination can be made easily by neutron diffraction. Investigations of both organic and inorganic compounds furnish important details on hydrogen bonds and on the thermal vibration of hydrogen atoms.

Other important structural problems, in which neutron diffraction can make substantial contributions, include investigations of order-disorder phenomena in alloy systems and determinations of the local arrangement of atoms in liquids and amorphous materials. In the field of magnetism the scattering of neutrons by magnetic materials offers a unique approach to the study of magnetic problems, because information is obtained on the magnetic properties of the individual atoms. Each type of magnetic material has a characteristic diffraction pattern, from which the magnitude and specific orientation of the atomic moments can be determined. Investigations provide details on magnetic phase transitions, magnetic structures, magnetic coupling, magnetic anisotropy, ferromagnetic and antiferromagnetic domains, and on the magnetic electrons within the atoms. Although the technique of neutron diffraction is relatively new, it has already been established as one of the most important methods of solid state research, because so many different phenomena can be studied in this manner.

The Georgia Tech reactor will offer excellent research facilities for a wide variety of investigations, and it should be very useful in augmenting the solid state program currently in existence. Several types of experiments are under consideration by members of the faculty and in some fields of research, such as neutron diffraction, equipment has already been designed. Two diffractometers, which can be used either for magnetic or non-magnetic scattering investigations, will be constructed, and the equipment will allow considerable flexibility for changing the conditions of the samples.



MICROSTRUCTURE OF A THERMET

THE WEDDING OF MATERIALS

by J. D. Fleming

THE PROGRAMS carried out in the Ceramics Branch cover a broad spectrum of research and development in metallury and ceramics.

Under government and industrial sponsorship, these programs consist of closely related, interdisciplinary studies at all levels from basic to applied research. Typical investigations include development of refractory insulation; structural components; and novel fuels for use in nuclear reactors; development of thermal protection systems; nozzle and nose cone materials; electrical insulation; and metal-ceramic structural composites for use in space propulsion systems; applied studies of solid state disorder-order transformations; stress distributions in metal fiber reinforced ceramics; high temperature solid state and liquid-solid

reactions, and radioactive tracer studies of gas permeation of porous refractory bodies.

A summary of one of these programs, that of exothermic metal-ceramic reactions, illustrates the nature of Ceramics Branch research and the application of solid state studies. The exothermic metal-ceramic reaction is typical of a general class of solid state and liquid-solid reactions which can be summarized by the unbalanced reaction

$$A + MO + I = M + MI + AO.$$

In this reaction, A represents an active metal whose oxide has a free energy of formation more negative than that of the metal oxide, MO. I represents an intermetallic compound former. These reactants combine exothermally at a characteristic temperature to produce a free metal, M, the active metal oxide, AO, and an intermetallic compound, MI. In many cases, the products of the reaction are desirable components of a refractory cermet and can be sintered or fused to a dense body by the heat evolved in the reaction. The body produced in this manner is referred to, for convenience, as a thermet.

Investigations have been made at Georgia Tech of aluminum and beryllium reduction of numerous oxides including those of silicon, chromium, nickel, tungsten, molybdenum, iron, cobalt, uranium, manganese, titanium, zirconium, vanadium, and hafnium. Reduction of these oxides in the absence of intermetallic compound formers leads to the free metal and the active metal oxide as confirmed

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DR. JULIAN D. FLEMING, JR. received the Ph.D. (chemical engineering) at the Georgia Institute of Technology. Fleming is originally from Rome, Ga., and his current fields of interest include high temperature metal and ceramic systems, nuclear fuels, tracer techniques, boiling and convective heat transfer. He engaged in development of refractory ceramic and metal systems for missile components. He developed refractory flexible electrical insulations and initiated and is now directing research in refractory nuclear materials. Fleming is studying tracer determination of diffusivities and permeabilities and investigating transient heat transfer in thin metal films. He organized and is instructing graduate and undergraduate courses in heat transfer, fluid flow, unit operations, metallurgy and nuclear engineering.

by x-ray and electron diffraction. Reduction of the oxides in the presence of elemental or chemically bound, as the oxide, silicon, boron, and carbon leads to the corresponding intermetallic compound. The ignition temperatures of mixtures of these materials typically range from 1500 to 2000° F.

Phase identification in the reaction products has proved quite difficult due to the intimate admixture of the metal and ceramic phases and the presence of quenched structures. Efforts are now underway to provide positive phase identification through electron microscopy and selected area diffraction with supplementary studies being made by electron microprobe analysis. Samples for electron microscopy and diffraction are being produced by extractive replication as well as by microtomy.

Investigations have been made of the influence of several system variables on the firing properties of thermets. The reaction has been demonstrated to be independent of an atmospheric oxygen supply by the fact that, for a given system, it occurs at the same temperature and equally as well in vacuum, argon, or air. Additional confirmation was provided by simultaneous differential thermal and thermogravimetric analyses of the thermet during ignition.

As would be expected, an increase in the specific surface area of the reactants, accompanying a particle size decrease, results in a lower ignition temperature, more complete reaction, and higher concomitant reaction temperatures. Surface temperatures in the reacting thermets have been measured in excess of 4000° F.

In order to study the mechanism of the thermet reaction, attempts are being made to follow the reaction in a hot stage metallograph. The problem of cinematography is somewhat complicated by the rapid evolution of light accompanying ignition of the thermet. Efforts are being made to accommodate this increase in light intensity, amounting to four orders of magnitude, by photosensitive control of a diaphragm in the optical train and by intense artificial illumination of the reacting thermet.

The thermets produced to date have displayed interesting properties such as moduli of rupture as high as 30,000 psi which are independent of temperature up to 2000° F. The thermets show some promise as refractory electrical components. By proper control of the reactants, resistors can be produced which display stable positive or negative coefficients of resistivity. Some thermet compacts act as rectifiers, having ten to one back to front ratios.

AN EXPANDING PROGRAM OF EDUCATION, RESEARCH

by Robert F. Hochman

A GREAT DEAL of metallurgical competence is possessed by staff members in the various disciplines at Georgia Tech. For many years metallurgical research and education has been conducted on a limited scale in the Schools of Chemical Engineering, Mechanical Engineering, and the Engineering Experiment Station. Generally, programs in metallurgy have been oriented to meet the needs of a specific discipline or project. The recognition of the important roll of basic metallurgy in these programs resulted in the addition of two metallurgists to the staff of the School of Chemical Engineering and the Engineering Experiment Station. With these personnel added to the capabilities already possessed by faculty and experiment station staff, an expansion of metallurgical education and research was planned.

Recognizing the need for metallurgists in the new highly technical industries of the Southeast, it was considered pertinent that a graduate educational program in metallurgy be initiated at Georgia Tech. In January of 1961, the graduate council approved a proposal by Dr. H. V. Grubb, Director of the School of Chemical Engineering, for a program leading to a Master of Science in Metallurgy. The undergraduate prerequisites for this program were based on seven courses presently offered in chemical engineering and supplemented by five additional courses deemed necessary to bring a student to the level of a baccalaureate degree in metallurgy. A partial listing of these courses includes general metallurgy, metallography, extractive metallurgy, mechanical and metallurgical testing, fabrication, heat treating, pyrometry, corrosion and physical metallurgy, the latter dealing with the fundamentals of atomic structure and properties of metals and alloys.

With this background a student may pursue the graduate curriculum provided the requirements in chemistry, mathematics and physics are met. Courses offered in the graduate

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program include high temperature metallurgy, powder metallurgy, advanced physical and mechanical metallurgy, advanced metallurgical thermodynamics as well as an x-ray course, Ceramics 640, taught by Dr. R. A. Young of the Engineering Experiment Station. These courses present the student with advanced concepts and theoretical studies in metallic structure and properties. In addition to providing the core for the master's program in metallurgy, these courses will also offer the necessary metallurgical background for programs planned in materials science, materials engineering and solid state sciences.

With the completion of construction of the Chemical Engineering-Ceramics Engineering Building in which nearly 10,000 square feet have been allocated for metallurgical laboratory space, it is planned that an undergraduate option in metallurgy will be added to the Chemical Engineering curriculum. With these added facilities and program requirements, it may be possible to make further additions to the metallurgical staff which, in turn, will lend a greater balance to the overall program.

In addition to other programs held on the campus, personnel in the School of Chemical Engineering have been active in metallurgical research for several years. Studies in oxidation and carbon monoxide attack have been directed by Dr. Robert Raudebaugh, a former staff member, and Dr. Waldemar Ziegler. At present, Dr. Niels Engel, one of the two metallurgy staff members, has initiated work on metallic bonding and prediction of metallic properties from the electron concentration in the solid state. He is also supervising studies of the effect of stress reversal on cooling velocity to aid in refining the thermal analysis for steels. In conjunction with a graduate-student fellowship sponsored by the Atlantic Steel Corporation, Dr. Engel is directing the work of Mr. Byron Davis, an M. S. candidate in metallurgy, in the investigation of nitrogen effects on the aging of steel. The author has been continuing the work of Dr. Waldemar Ziegler and Dr. William Seagraves on the elevated temperature attack of carbon monoxide on iron, nickel, cobalt and their alloys. To further this study it was necessary to compute certain thermodynamic functions for iron and nickel carbonyl in the ideal gas state. Mr. Fred Haynie a chemical engineering graduate student, has prepared the data with the aid of the computer center, and a paper based on this work is awaiting publication. Mr. Arthur Cox, candidate for a Master of Science in metallurgy, is presently continuing this investigation by studying

the initiation of the carbon monoxide attack. Additional technical guidance and equipment for this program is being provided by Dr. Edwin J. Scheibner of the Engineering Experiment Station staff. The unusually broad scope of this study will require the use of electron microscopy, x-ray diffraction and the utilization of an ultra-high vacuum system. At present, the author is also director of a project involving the investigation of thermoelectric materials. To date the major portion of the program has been devoted to the study of surface contamination and surface film growth with its attendant effects on joining of thermoelectric elements.

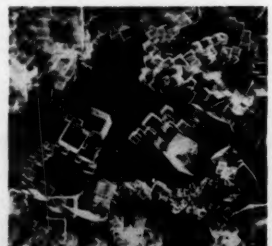
In addition to the academic program in metallurgy, Dr. Engel and the author have been active in providing metallurgical information and assistance to local industries. Dr. Engel serving as the chairman of the educational committee of the Atlanta Chapter of the American Society for Metals has aided in presenting several educational programs for ASM members and personnel of local industries. The author acting as chairman of the 1961 Southern Metals Conference worked with the southeastern chapters of the American Society for Metals in presenting an exposition and technical program in Atlanta this past spring. The technical portion of the program featured fifty-two papers in the various areas of metallurgical science presented by men from all over the country. In all, nearly three hundred metallurgists and material engineers attended.

With these new programs and added interests the impetus has now been provided for the continuing growth of metallurgical education and research at Georgia Tech.

DR. ROBERT F. HOCHMAN's special fields of interest include high temperature metallurgy and ceramics, crystal mechanics, corrosion studies and materials kinetics. The Chicago native received the B. S., M. S. and Ph.D. (metallurgical engineering) at the University of Notre Dame. He was both a research and teaching fellow at Notre Dame and later taught basic and advanced metallurgy at the Michigan Station University Extension in Benton Harbor, Mich. He did research work in metal-ceramic interactions at the Minneapolis Honeywell Research Center, Hopkins, Minn. Hochman also served as consultant to many small firms in the Michigan-Indiana area, He came to Georgia Tech in 1959. In April, 1961, he was general chairman of "Metallorama," the 1961 Southern Metals Conference in Atlanta.

EDITED IN RETROSPECT

THIS IS scheduled to be the first of two issues on a single subject—solid state sciences—a subject that as much as any other cuts across departmental lines at American universities. For instance, in this issue you will find articles on six different disciplines at Georgia Tech. In the next one, another six or seven disciplines will be featured. In this manner we hope that our readers may get a better picture of how Georgia Tech is attempting to keep abreast of the changing world of science and technology in both its educational and research programs. Another interdisciplinary area—systems engineering—is already scheduled for the April issue of this magazine. Incidentally, the photographs on this page are really micrographs of solid materials, taken by one of Georgia Tech's electron microscopes.



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